SNOW AND ICE CONTROL IN CALIFORNIA

By
Carl Forbes, Carl Stewart & Don Spellman

To Be Presented at The Highway Research Board
Symposium on Snow Removal and Ice Control Research
Hanover, New Hampshire
April, 1970

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

Reference: "Snow and Ice Control in California"

Part I, Present Operations, by Carl E. Forbes, Maintenance Engineer, California Division of Highways

Part II, Valley Bridge Deck Icing, Special Studies, Bridge Department, California Division of Highways

Part III, Deicing Chemicals, by D. L. Spellman, Assistant Materials and Research Engineer, Materials and Research Department, California Division of Highways

Abstract: Part I - Present Operations

While much of California is free from snow and ice conditions, there are many areas in the state where significant amounts of snowfall occur and where frost and ice are common during the winter months. Some kind of snow removal operation is performed on about 4600 miles of the state system. Snowfall ranges from a trace up to 750 inches annually.

Because of the vast areas to be covered and differences in the type of equipment needed for the different kinds of snow conditions, it is difficult to shift equipment from one location to another. Snow removal policies require prompt removal of snow down to the bare pavement. Under certain conditions however, chains may be required, and sand and chemical deicers are used to keep the pavement free of icy spots. Because icy spots can occur in shaded areas, during brief periods of lowering temperature, on bridge decks and where drainage may cross the road, constant patrols are necessary to locate and treat these slippery areas.

Equipment used in snow removal operations includes 73 rotary plows, 528 displacement plows, 140 four-wheel drive motor graders, and various types of sand/salt dispensers mounted on trucks.

Last year, 22,000 tons of salt were purchased for snow and ice control throughout the state. About 270,000 tons of various types of abrasives were made available for use.

Abstract: Part I Continued

Dormitories are provided to house men during the winter months at various points throughout the state. One such larger installation houses about 70 men during the peak period, and this crew is responsible for snow removal on 22 center line miles of 4-lane divided freeway above an elevation of 6500 feet.

Increasing use of recreational area has increased the need for more extensive snow removal operations. In some areas, snow cannot be just pushed aside, but must be hauled off to a disposal point. New sections of roads now kept open pose avalanche problems. We have been able to keep pace by improvements made in equipment which is more efficient. In one case, the efficiency of one Snogo was increased 93% over the original machine by switching to diesel power and improving the type of cutter auger and blower system. Other specialized units have been employed for snow removal, and coordination is achieved through a radio net covering 85 Highway Superintendent's offices as well as the eleven District offices and Headquarters in Sacramento. Most of the individual units are radio equipped and operators can communicate with each other directly or through the foreman's mobile units and the Superintendent's office. On-the-spot conditions are relayed to a central office where local news media are kept advised of any changing conditions.

Part II - Valley Bridge Deck Icing

Areas where bridge decks may frost or ice over while adjacent pavement is frost-free presents a special problem in ice control. Some means of preventing this potentially dangerous condition is sought.

Maintenance crews can sand or salt frosty decks <u>if</u> they know where this condition occurs, and <u>if</u> there were enough men to cover all the bridges immediately. Detection of a potential frost condition is, therefore, desirable. In the absence of a warning system, maintenance crews have adopted alternative measures which includes

Abstract: Part II Continued

regular applications of salt and sand and salt solutions that prevent the formation of frost. Application of saline solutions have, for example, been found to be effective for a period of up to three days in preventing frost formation. This operation, while successful in many ways, has resulted in what is considered premature deterioration of concrete structures. As a result, other ways to combat the problem are sought.

In one case, selected spans on three structures were enclosed with urethane foam sheets. Electric heating cables were installed in some of the enclosed spans which were activated by a thermostat when the temperature was below 38°F.

Ice detector/warning sign systems were installed on one bridge to evaluate motorist reaction to "Icy Bridge" warnings. Performance of the detectors and motorists' reactions were both disappointing. In the case of the former, the mild weather prevented a thorough check on operation of equipment, but it appears that the type of detector used is not suitable for use in the valley areas because there is not enough moisture to act as an electrolyte on the sensor. Continued evaluation is planned during the 69-70 winter. Motorists' reaction to warnings was not outstanding with only 24 to 66% showing any positive reaction.

Part III - Deicing Chemicals

Corrosion of steel and other distress in concrete decks which were salted to control ice and snow prompted a search for a noncorrosive deicing chemical which would compete in cost and effectiveness with the chloride type deicers currently in use. Seventeen candidate chemicals were compared on the basis of:

1. Their effectiveness in melting ice, frost, and snow

2. Their effectiveness in preventing frost or icing

Abstract: Part III Continued

3. Their effect on construction materials such as concrete and steel

4. Their effect on the ecology and toxicity to humans

5. Their effect on skid resistance

While a variety of tests were performed, not all tests were performed on each chemical.

Ice melting tests were found useful in laboratory evaluation, but lab performance is not necessarily representative of what may occur in the field.

Large crystals of an agent can, for example, "bore" through a snow pack and be effective in breaking up the structural layer for subsequent plowing. Small grained deicers may effectively melt ice, but lack the "boring" property described. The ideal "grain size" may depend upon the type and condition of the ice or snow to be removed.

As described in Part II of this paper, ice prevention can be an important factor in controlling frost in valley areas. One chemical investigated tetra-potassium pyrophosphate (TKPP) appeared to have good "holding" power in that it was able to prevent the reoccurrence of frost for a comparatively long time.

Since TKPP performed relatively well in the corrosivity to steel and concrete tests, and posed no specific problem regarding toxicity, it was selected for field skid testing as well. A concentration of either a 30% or 60% solution caused a temporary reduction in skid resistance as did a solution of calcium chloride, but the simultaneous addition of sand should keep skid resistance at an acceptable level at all times. Work is continuing.

Key Words: Snow and ice control, bridge decks, deicing, deicing agents

ACKNOWLEDGMENT

The work reported in Part III of this report was performed in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, Agreement No. B-4-3.

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those held by the Bureau of Public Roads.

Acknowledgment is also given to Mr. R. F. Stratfull under whose direction the work in Part III was performed, and who also was instrumental in the preparation of this report.

Table of Contents

SNOW AND ICE CONTROL IN CALIFORNIA

By
Carl E. Forbes, Carl F. Stewart, and
Don L. Spellman*

Part I
Present Operations
By Carl E. Forbes

California lies between the 32nd and 42nd parallels of latitude. Elevations range from more than 200 feet below sea level in Death Valley to over 14,000 feet above sea level in the Sierra Nevada and Cascade mountain ranges. Approximately one-fifth of the state lies above the 5000-foot elevation level.

This combination of range in latitude and elevation results in a multitude of different snow conditions. Although 5000 feet is generally considered as the normal snow line, occasional heavy storms will fall as low as 500 to 1000 feet above sea level. Although this is particularly true in the northern part of the state, it is not uncommon in the high desert region.

Snow removal operations are performed on some 4600 miles of our state highway system. The extent of this operation ranges from the nuisance variety to very serious conditions, with snow fall ranging from a trace to over 750 inches of annual snow fall at such locations as Donner Summit on Interstate 80.

Because of the extent and variation of the snow removal operations in California, it is almost impossible to concentrate equipment and extremely difficult to shift equipment from one location to another. Snow is removed from the Laguna

* Maintenance Engineer; Senior Engineer, Special Studies, Bridge Department, and Assistant Materials and Research Engineer, California Division of Highways, respectively.

Mountains east of San Diego and just north of the Mexican border all the way to the Oregon border. Storms in the southern part of the state will generally deposit snow in fairly concentrated areas and generally above the 5000-foot level.

The mountain ranges lying to the north and east of the Los Angeles basin are heavily used for recreational purposes and have many miles of highway above 7000 feet. Along the Sierra Nevada range, as you progress to the north, the snow line steadily decreases with the increase in latitude. On many occasions, heavy snow fall will occur in the entire northeastern corner of the state.

Temperatures during the winter have been measured well below -40° and high winds frequently cause blizzard conditions on trans-Sierra routes and on U.S. 395 just east of the summit of the Sierra Nevada mountain range.

The quality of the snow itself is quite variable depending on the location in the state. As an example, as a general rule, the snows on the west slope of the Sierra Nevada range will be very wet while those on the east slope will be extremely dry.

As a guide to our crews working in this operation, we have defined the level or quality of maintenance as expected in snow removal as follows:

"SNOW REMOVAL

"Snow should be removed from state highways as it falls, except on roads having extremely light winter traffic, which are closed after the first heavy snow.

"Snow should be removed to the pavement surface for the full width of the traveled way. Widening to provide storage space for the next snowfall should immediately follow traveled way snow removal.

"Areas within the right of way in front of stores, resorts, service stations and other roadside business establishments which serve the general public should be kept clear of snow when such areas have been graded and paved by the owner of the abutting property, so that heavy equipment can be operated.

"Areas within the right of way adjacent to the traveled way which have been established to provide for public parking, such as locations where the public has access to snow sports, should be cleared. Snow should be removed from established public parking areas after the highway is cleared and equipment becomes available.

"State forces will not remove snow from approaches leading from the traveled way to private property, but will operate so as to cause the least inconvenience to property owners. The windrow placed in front of approaches should be removed.

"State forces are to assist local authorities in opening public road connections.

"Chains shall be required when, in the judgment of the maintenance supervisor on duty, the road surface becomes unsafe for vehicular traffic due to snow and ice conditions.

"ICE CONTROL

"Where ice, frost or snowpack causes slippery pavement, abrasives and/or chemicals should be applied. The treatment to be used shall be determined by the immediate supervisor in charge of maintenance of the particular section of highway. In areas subject to heavy snowfall, prolonged freezing temperatures and heavy traffic, abrasives and/or chemicals should be spread on the pavement at the beginning of a snowstorm to prevent a snowpack from forming and to facilitate snow removal.

"PATROL

"On routes where freezing conditions are anticipated, special patrols should be scheduled on a continuous basis for the detection and correction of slippery conditions.

"BRIDGES, SHADED AREAS, AND OTHER KNOWN ISOLATED LOCATIONS OF ACUTE ICING CONDITIONS

"Abrasives and/or chemicals should be applied at the beginning of a storm or whenever icing appears imminent.

"Bridges which have a tendency to ice, especially when the approaches may be dry, should be given high priority attention both in patrolling and ice and frost prevention."

Under average winter conditions, sufficient plowing equipment is assigned all snow satations to handle the amount of snow normally expected. Much of this equipment is geared to year round use. This includes motor graders, dump trucks and front end loaders.

On lightly traveled roads at lower elevations, snow equipment generally consists of 2-ton or 4-ton dump trucks and a motor grader. With the addition of medium size reversible snow plows the trucks used during summer weather are sufficient to remove the light snow or slush that falls. During cold weather, a tailgate type hydraulically operated chip spreader can be added for sanding and salting icy or frosty spots on the roadway. This combination can handle up to 10 or 15 miles of low elevation snowfall without much trouble providing the average daily traffic on the route is light.

On the main trans-Sierra artery, IS-80 between San Francisco and Salt Lake City, we have constructed three major snow removal stations to house snow equipment and personnel to insure that bare pavement will exist as often as is humanly possible during any 24-hour period. At these stations, both multipurpose and highly specialized snow removal equipment is assigned for winter work.

We presently operate 73 rotary snowplows of various makes and ages. It is our practice to assign the newer rotaries to those areas having the trunk line through routes north to Oregon and east to Nevada with the older rotaries working on routes of low traffic density and those which by policy have winter closure points dead-ending somewhere short of the summits.

There are 528 displacement plows available for operation. These plows are fitted to a variety of trucks of from 2 to 8-ton capacity. In addition, there are 140 four-wheel drive motor graders available for snowplow work. These graders are equipped with large hydraulic reversible push plows along with the grader blade that is used for removal of packed snow and ice.

Various combinations of sand, cinders and salt are used for icy pavement control depending on the location of the highway and/or bridge decks being treated. This material is spread with spinner type chip spreaders, some of which are mounted under the tailgate of the dump trucks and some of which are bunker type of 5-ton capacity permanently mounted for the winter onto the truck chassis. Last winter, 22,000 tons of rock salt was purchased for use on snowpack and ice removal throughout the state. Abrasives of varying types such as sand or cinders were either purchased or made, distributed and stored, ready for use in the amount of

270,000 tons. Two of our districts, one in the northern end of the state and one on the eastern side of the Sierra Nevada Mountains, operate their own screening plants during summer months for producing screenings for winter use. Screenings are obtained from natural lava pits where the supply is practically unlimited and where the purchase of sand for this purpose is not economically practical.

Since the advent of raised pavement markers, the Department is currently experimenting with rubber snowplow blades for snow removal in the lower elevations. Raised markers are being used up to approximately the 2500-foot level. From data that will be collected this winter, a better indication of the value of rubber blades will be obtained.

Snow removal in the higher elevations in Southern California is conducted as it is elsewhere in the state, on a 24-hour basis to insure movement of the largest concentration of vehicles in the nation. With the exceptions of Cajon Pass, Route IS-15 and the Ridge Route IS-5, nearly all other routes subject to snowfall lead to or are in recreation areas.

Because of the snow sports available in the mountain areas of the south and the thousands of persons wishing to take advantage of the numerous, close-in winter recreation areas, one of the major problems is traffic control. In this respect, the California Highway Patrol works in close cooperation with our Division of Highways personnel.

Facilities for the maintenance of an all-year route with our bare pavement policy are necessarily large and complex. One example is our Kingvale station which was constructed in 1961. At this time, it consists of a three story dormitory which includes a large kitchen-dining room, recreation room and individual bedrooms to house approximately 70 employees. The other facilities include a 32 bay truck shed with foreman's office, mechanics shop and radio communications equipment room; a carport for private cars, a storage building and a sand house with a separate gravity feed bunker for salt storage.

During summer months, the station is staffed with a foreman, an assistant and 6 maintenance men. In the winter, limited term personnel are recruited and supplemented by men from our valley crews as needed. The winter crew at this station will consist of between 40 and 70 men depending on the intensity and duration of a storm. This station maintains 22 center line miles of 4-lane divided full freeway above the 6500-foot elevation level.

In addition to routine maintenance equipment, the Kingvale station uses approximately 30 pieces of heavy snow removal equipment. Among this equipment are 9 four-wheel drive motor graders, 6 modern rotary snowplows and 8 trucks varying in size from 2 to 6 tons equipped with displacement plows.

One problem which is increasing with the growth of recreational resort areas is the necessity to dispose of snow by means other than plowing or blowing. Growth such as that found in the Lake Tahoe area of the state and in the Southern California resort areas requires that snow be hauled to designated disposal sites. This operation requires the use of rotary plows equipped with directional chutes for loading. Trucks for hauling are the conventional 3 axle, 10 cubic yard type. At the dump sites one or two tractor dozers are employed to stockpile snow and keep the disposal site in traversable condition.

At times as many as 40 dump trucks are used for this purpose. On an average it takes a rotary plow 3 to 4 seconds to load one truck after the snow has been windrowed.

Of the nine trans-Sierra routes, four are closed with the first heavy snowfall of winter. Closures for the most part are in the 7000-foot elevation range. Most of these routes are closed from November through May.

With the end of winter in the higher elevations, tractor-dozers and rotary plows are used to remove the snow from the routes that have remained closed since the beginning of the snow season. Steady improvements in the capacity of snow removal equipment, particularly rotary plows, have reduced the time it takes to open these passes to a period that will average close to three weeks working one shift a day. Just a few years ago, crews worked two or three shifts a day to accomplish the same goal in a three week period.

Avalanche control is necessary on U.S. Highway 50 during winter months. As overhanging cornices build up several hundreds of feet above the highway, artillery fire and explosive shells are used to intentionally trigger avalanches at pre-selected times with the road temporarily closed. Two locations on this route have permanent platform gun mounts for a 75mm recoilless rifle. The remaining two of four locations can be reached with a portable compressed air gun. To date, we have been successful in preventing any serious accidental avalanche problem.

Our Equipment Department works in close cooperation with field maintenance forces on the upgrading and improvement of all equipment used for maintenance of highways.

As an example, with the completion of a four-lane freeway on IS-80 over the Sierras, it was apparent that greater efficiency in the use of rotary snowplows would be necessary in order to keep the cost of snow removal work within reasonable limits and at the same time retain the high standard of traffic service to which the public had been accustomed.

One of our older Snogos was rebuilt and equipped with a diesel engine for powering the augers and blower system. Later improvements to the cutter augers were made. A Robla (spiral reel) type auger was substituted for the original conventional 3 auger system. When measured in tons per hour of snow removed, the increased efficiency of the modified Snogo was 93% over the original machine. Since this first unit was placed in operation, a total of twenty older Snogos have been rebuilt.

To eliminate continued replacement of bottoms in bunker type sand trucks, which rust through rapidly from salt, the Equipment Department is now furnishing bunkers with stainless steel.

Specialized units which have proven to be labor saving in snow removal and ice control work are Hydro sanders which replaced the old Missouri type traction driven sanders; air operated snow post drivers with a magnetic holder built into the post leads; and "B" type hydraulic reversible plows with a standardized frame and hoist assembly that is readily adaptable to several different truck sizes. This plow, working in 4 inches of snow, will displace approximately 2290 tons of snow per hour when traveling at a speed of 25 MPH. We are presently experimenting with a hydraulically operated vibratory grader mouldboard. This is mounted on a four wheel drive grader for use in removing ice pack from the pavement.

Most of our snow removal equipment is radio equipped. Base stations are maintained at each of 85 Highway Superintendents' Headquarters Offices in the eleven district offices as well as Headquarters Office in Sacramento.

Basically, operators of snow removal equipment can communicate directly with each other, with the Foreman's mobile unit, and the Superintendent's office.

Road and weather information during winter months is reported by each foreman on a daily basis. This information is accumulated in the superintendent's territory office and relayed to a district office. Here it is again accumulated and relayed via tape or teletype of the Division's Headquarters Office.

Local news media are kept advised frequently of any changes by District and/or Headquarters Office.

Essentially California operates a vehicular and base radio communication system and an opertional micro-wave telephone system through various base and relay stations.

Due to the amount of traffic and the almost continuous need for emergency work in the Los Angeles metropolitan area, the District Cummunications Department there works on a 24-hour basis 7 days a week the year round.

Headquarters Communications will be on the air during all storms in winter months on a 7-day, 24-hour basis.

During these periods, information is disseminated to 14 broadcast stations hourly, who in turn transmit road conditions to the public. In addition, the Division maintains automatic telephone answering equipment located in several areas throughout the state. Information for this service is updated on a continuous basis.

In the four districts with most of our snow removal work, our foremen and superintendents' cars and pickups are equipped with a California Highway Patrol radio. The Patrol is also equipped with our channel, and during emergencies, this expedites icy pavement control and similar services.

The Division also maintains direct teletype communications with the States of Nevada, Oregon and Washington for the exchange of road and weather reports.

SNOW AND ICE CONTROL IN CALIFORNIA

Part II
Valley Bridge Deck Icing

By Carl F. Stewart*

PROBLEM

In California's central valley area, where the temperature seldom falls below 20°F, flash frost or ice forms on bridge decks but not on the approach roadway. This spot icing becomes a hazard to unsuspecting motorists. With the increase in speed on modern freeways, the records show a sharp increase in accidents in the last few years due to this phenomena.

The present motorist warning system of impending icing danger is a standard "Slippery When Wet or Frosty" metal sign. This is ineffective, primarily because the sign is continuously visible to the motorist, even in the summertime, and as such becomes an accustomed standard fixture along the roadway.

Since icing is intermittent, regular sanding patrols are not maintained. This leaves maintenance forces under a handicap in not being on the spot when needed because icing cannot be generally predicted. (It usually occurs in the early morning hours before the normal working day begins.)

The icy bridge deck problem in the valley area is usually handled by one of the following procedures:

1. When there is a high potential for deck icing, a crew will stand by to apply a salt-sand mixture if necessary.

2. The Highway Patrol informs local maintenance personnel after ice has formed.

*Senior, Special Studies, Bridge Department, California Division of Highways

3. An ice preventive saline solution is periodically sprayed onto the decks. Each application is effective for approximately three days.

Adverse ramifications of these procedures are:

1. Bridge deck salt-sanding is an additional task to valley maintenance personnel and results in extensive overtime work.

2. Bridge deck salt-sanding in a valley environment is usually done under the hazardous conditions of darkness, foggy weather, and high speed traffic. (The latter is usually more of a hazard to valley sanding crews than mountain crews because of the valley motorist's unawareness of an icing problem.)

3. When highway patrolment report icing, it usually means the deck will have been iced for considerable time before maintenance personnel arrive to salt-sand.

4. The saline solution preventive method accelerates deck deterioration.

5. Regardless of the application method, deicing salts are causing deterioration in decks that have heretofore been maintenance-free.

Basically, the valley bridge deck icing problem falls into two areas:

1. Safety (Motorist and Maintenance)

2. Premature deterioration

RESEARCH

With an objective of improving both motorist and maintenance personnel warning systems and eliminating deicing chemical deterioration, a research project was initiated in 1968. The research consisted of: (1) enclosing the underside of six T-girder spans to form simulated box girder spans; (2) providing heat in three of them; (3) providing a motorist warning sign which is readable only when illuminated; and (4) installing telephone relay systems to local maintenance personnel. The sign and telephone relay systems are activated by ice detecting mechanisms.

Enclosures

Two spans of each of three structures were enclosed by attaching one inch thick urethane foam sheets to the bottom of the girders. Mastic between all joining sections made the enclosure airtight. Low resistance electrical cables provided heat in one of the two spans so enclosed on each structure. The purpose of a nonheated span was to determine the effectiveness of dead air space under the deck in preventing frost from forming on its surface. Heat in the heated span was controlled by a thermostat and was on when the outside ambient temperature was below 38°F. The amount of heat furnished could be manually controlled from 2-1/2 to 10 watts per square foot of deck area.

Thermocouples were placed in the surface and soffit of the deck in the enclosed spans and an adjacent nonaltered span, in the open space of the enclosed cells, and in the air alongside the bridge. Honeywell 20-point Recorders continuously recorded the temperatures on a 5-minute cycle from midnight to 10:00 am each day during the three months of potential frosting: December, January, and February.

Ice Detectors

Ice detectors manufactured by three different companies were installed: Nelson, Econolite, and Holley. Sensing transducers of the detectors were placed at the deck surface in the center of the inside traffic lane. The detectors were connected to the motorist warning sign and to maintenance telephone relay systems. The Honeywell Records monitored the detectors.

Motorist Warning

An extinguishable message sign was installed on an approach 600 feet from one of the bridges. The 8-inch high "ICY BRIDGE" letters of the sign are illuminated from behind by flashing flourescent tubes. When the tubes are not lit, the letters blend in with the blank face of the sign, thus making the message indiscernible when the sign if "OFF."

Motorists' reaction to the sign was documented by a two-man team; one at the sign and one at the bridge. They recorded any evidence of reaction: brake lights coming on or motor deceleration.

Maintenance Warning

Ice detecting mechanisms were connected, through a telephone relay, to a bell and flashing light in a Highway

Patrol Office in one area and in a continuously manned Bridge Tender's Office in another. Local Highway Maintenance personnel are notified when a system is activated.

RESULTS

Due to several reasons - shipment delays, priorities, high water, failures, etc., - the entire installation was not completed until January, 1970. Most of the system, however, was operating during the 1968-69 winter. Not too much was learned during this first winter though because it was a very mild one with respect to frosting or icing conditions. The air temperature dropped below 30° only twice during the winter; the minimum was 26°. Consequently, very little pertinent data are available from the 1968-69 winter. Data are being collected during the 1969-70 winter, but will not be analyzed in time to be included in this report.

There was a sufficient number of days with the minimum temperature in the low 30's, low enough for frosting to occur, during the 1968-69 winter to determine that the deck surface temperature over the enclosed but unheated spans followed very closely the deck surface temperature over the open span. In other words, the entrapped dead air space of the enclosed span had little effect on the deck surface temperature.

There was about an 8° temperature differential between the surfaces over the heated and open spans when 10 watts per square foot of deck area were being applied to the heated cells.

During three occasions when the weather forecast called for heavy frost, the observation team observed motorists' reaction to the warning sign. On each occasion the temperature was low enough for frosting, and frost did form on the rails, but none formed on the deck. Since there was evidence of frost, the sign was turned on manually to observe motorists' reaction to it. On one occasion the reaction was very poor. Of 105 cars only 24% reacted; of 60 trucks, 23% reacted. On the other two occasions the reaction was better, but still not outstanding: 44% and 56% reaction by autos and 29% and 66% by trucks. Buses were included as trucks during the observations. Of three school buses that approached during one observation, only one driver made a discernible reaction: he applied his brakes <u>after</u> he was on the bridge.

The very mild winter prevented a thorough check on the ice detecting equipment. From the limited experience with it, however, it appears that the frost detectors are not effective on bridge decks in California valley area. The problem is in the moisture detecting sensor. It appears that it is possible for sufficient moisture to exist on the deck for frosting but insufficient moisture on the detector's heating element sensor to act as an electrolyte between the electrodes. It is logical that moisture would evaporate quicker from the heating element than it would from the deck at low temperature. When there is an abundance of moisture this difference in evaporation rate would not be a problem. But when there is a minimum of moisture it is a serious problem. Bridge deck frosting usually occurs with little moisture. Unsuccessful attempts were made to correct this problem by lowering the temperature of the heating element. More work along these lines is planned for the 1969-70 winter.

CONCLUSIONS

Based on the data collected thus far, the following conclusions seem warranted. It should be recognized, however, that they could be modified when the total data are analyzed or when colder temperatures are experienced.

1. Dead air space under a deck, as occurs naturally in a box girder type structure, has little effect on deck surface temperature.

2. On the average, less than 50% of the motorists react adequately to an illuminated "ICY BRIDGE" warning sign.

3. Conditions which lead to frosting on bridge decks in the California valley area appear to lie within ranges that are too sensitive for the presently available ice detecting mechanisms.

SNOW AND ICE CONTROL IN CALIFORNIA

Part III
Deicing Chemicals

by Don L. Spellman *

INTRODUCTION

Because of the increasing use of chloride type deicing salts, corrosion of bridge deck steel has resulted in a substantial amount of spalling of the concrete and subsequent repairs[1-5]. As a result of the bridge deck reinforcing steel corrosion, some extensive studies have been made of deicing chemicals other than chlorides[6,7,8,9].

When considering alternative deicing chemicals, several factors have to be considered, such as (1) effectiveness and cost of melting ice, frost, and snow; (2) effectiveness and cost of preventing ice and frost; (3) effect of the chemical on the ecology; (4) handling hazards; (5) corrosivity of the chemical to metals; (6) effect of the chemical on the durability of construction materials, such as concrete and bituminous products.

Because of the preceding areas of consideration, our research effort for selecting an alternative deicing chemical involved comprehensive testing and investigation.

*Assistant Materials and Research Engineer, California Division of Highways

SUMMARY

A total of 17 different candidate chemical deicing agents were subjected to various laboratory and field tests. While all agents were not subjected to the same array of tests, those chemicals tested were as follows: sodium chloride, calcium chloride, sodium formate, tripotassium phosphate, tetra-potassium pyrophosphate, Formamide, Urea, sodium acetate, sodium benzoate, calcium formate, magnesium sulphate, tri-sodium phosphate, potassium oxide, sodium silicate, sodium sulphate, sodium pyrophosphate, and sodium hexametaphosphate.

Laboratory Ice Melting Tests

The results of the laboratory ice melting tests show that the melting rate of ice by various chemicals can be mathematically described. Also, the slope of the line in the regression analysis is apparently an "efficiency" term that can be used to compare various chemicals. However, the actual melting of ice is only applicable to a laboratory comparison, and not necessarily representative of field performance.

Laboratory Ice Prevention Tests

Concrete slabs were cast and wetted with solutions of various chemicals to determine the parameters of ice and frost prevention. The slabs were cooled to zero degrees F, placed in a 85%-95% R.H. room and observed for the formation of ice and frost. Other than sodium chloride, tetra-potassium pyrophosphate (TKPP) was one of the better ice prevention chemicals tested in this manner.

Field Skid Testing

Limited skid tests were comparatively performed using solutions of sodium chloride and tetra-potassium pyrophosphate (TKPP) on an average-textured concrete pavement. It was found

that a 60% concentration of TKPP temporarily reduced the friction factor of the concrete pavement. However, with a standard spread of sand being applied to the solution on the pavement surface, there was a significant recovery of skid resistance. Even without sand, the skid resistance, in all cases, recovered with time as a result of the evaporation and absorption of the water. A 30% solution of TKPP with and without the sand application has about the same effect on skid resistance as a 30% solution of sodium chloride.

Effect of the Chemicals on Air Entrained Concrete

The effect of tap water and saturated solutions of sodium chloride and sodium formate on concrete was investigated. Sets of concrete cylinders containing 4-1/2 and 7 sacks of cement per cubic yard were alternately immersed in each solution, then oven dried at 140°F. Sodium formate caused rapid disintegration of the concrete. Visual observation and concrete length measurements indicate that sodium chloride is slowly causing disintegration, while as expected, there is no measurable effect of tap water. Similar testing has been initiated using a saturated solution of tetra-potassium pyrophosphate (TKPP), and thus far, the only conclusion that can be made is that TKPP does not attack concrete as rapidly as sodium formate.

Effects of the Chemicals on Steel

All deicing chemicals tested that were dissolved in distilled water were corrosive to steel. Depending upon the concentration, urea was more corrosive to steel than sodium chloride. To simulate concrete, lime was added to the corrosion test solutions. It was then found that sodium chloride was the most corrosive followed by urea, sodium formate, and the least corrosive to steel being TKPP. However, the lime water containing all chemicals should be corrosive to zinc and aluminum because of the high pH. Because of the possibility of the nitrogen type of deicers penetrating into cracks which are usually filled with soil or sand, these chemicals may be converted into highly corrosive nitrates by bacterial action.

Ecology and Toxicity

Numerous chemicals were investigated for toxicity and their possible effect on the ecology. From a toxicity standpoint, TKPP should be handled in the same manner as sodium and calcium chloride. From an ecology standpoint, nitrogen compounds, or those chemicals that can degrade into nitrogen compounds, are the most likely ones that could "burn" plants and stimulate algae growth in adjacent streams. In addition, the nitrogen compounds, as nitrates in ground waters, are being currently studied by others for their toxic effects on infants[14]. Phosphate compounds appear to be less potentially active in their effect on the environment than are nitrogen compounds.

Laboratory Ice Melting Tests

In California, deicing chemicals are used in the following ways: (1) They are spread on the pavement or bridge deck to prevent the formation of ice and frost; (2) at the beginning of a snow storm, they are spread on the surface to partially melt the snow and also to break the adhesion of the snow to the pavement surface; (3) during and after a snow storm, the crystalline chemicals are spread on the surface to melt and break up the structural properties of the compacted snow.

Two methods for the application of the chemicals have been used: (1) the salt is dissolved in water and the solution is sprayed on the pavement to prevent the formation of ice and frost, and (2) salt crystals both with and without sand or cinders have been used for frost and ice prevention as well as for the removal of compacted snow.

While it is most desirable to duplicate field conditions in the laboratory tests, this test program did not duplicate field conditions in two important areas: (1) the effect of traffic which is significant, and (2) the actual process of formation of ice and frost as related to relative humidity and other changing weather factors.

The general method used in testing for ice melting capabilities was previously reported[9] except that larger quantities of distilled water were used. Also the melted ice at the prescribed test temperatures was measured at melting time intervals of 5, 10, 15, 30, 60, and 120 minutes, and also at 24 hours.

The ice melting test data were first graphically plotted, and it was observed that the quantity of ice melted was related to the base ten logarithm of the test time. By the method of least squares, a regression analysis was made of all ice melting data. The resulting equations are shown on Tables 1 through 3. Care should be exercised when computing the depth of ice melted at time intervals of less than five minutes, or greater than 24 hours. For time intervals of five minutes or less, the measurements were relatively inaccurate because the amount of melted ice was usually very small. The measurements generally did not extend beyond a 24-hour period.

As shown in Tables 1 through 3, the deicing chemicals can melt a considerable depth of ice, given sufficient time. It is also of interest to note the laboratory results that show sodium chloride at the laboratory test temperature to be greatly superior to calcium chloride. What this test does not demonstrate is the ability of a large crystal to "bore" through the ice and thus break up its structural properties so that chain action can accelerate its transformation into "slush." The slush can readily be plowed or otherwise removed from the pavement.

As indicated by the results of the regression analysis, the most apparent indication of ice melting efficiency is the first constant in the equation, that is, the multiplier of the time variable. In effect, this constant is the "slope" of the line, and also a mathematical definition of the rate of melting. The greater the numerical value of this constant, the faster the ice melts. It should also be pointed out that the "efficiency" of melting rate constants as shown in Tables 1 through 3 will also vary with the physical size of the grains of the chemical. It is believed that a grain of high bulk will continually be in physical contact with the ice interface, and the melting rate will be more rapid because of the high concentration of the chemical at this point. As a result, the ice melting constants not only can be used to compare chemicals, but may also be used to evaluate the relative efficiency of various grain sizes for a particular chemical. The relative use of grain size of the chemical could be related to its use; for example, within limits, a small grain size may be more appropriately used for direct application to thin ice on the pavement surface. Conversely, a large grain could be used during the snow removal operation because it would bore through the thicker layer of snow more rapidly. In other cases, a mixture of fine and coarse grains may produce the best results.

Laboratory Ice
Prevention Tests

In order to determine if the alternative chemicals could prevent the formation of ice, 34 concrete slabs were cast, each having a surface area of approximately 130 sq.in. and depth of 2-1/2 inches. These slabs were made from a typical 6-sack concrete mix design using a local stock aggregate and 4.7% entrained air. Concrete was consolidated by means of vibration and the surfaces of the slabs were given a surface texture similar to a typical in-service bridge deck. To accelerate the tests, the slabs were moist cured for a minimum of 16 hours and then steam cured for 17 hours prior to applying the test solutions.

All slabs were identified and areas outlined on each slab surface for tests with the British Portable Friction Tester. Friction tests were performed initially on each slab by the conventional test method using water. After applying solutions, these friction tests were performed on slabs that had been frozen and then allowed to warm to a temperature of about 45°F. The purpose of these tests was to determine what lasting effects, if any, the solution might have on skid resistance. The numerical results are not considered conclusive as there was difficulty in duplicating the measurements.

Six slabs were tested in each test set. In each set, one slab remained untreated as a reference or control slab.

The concrete slabs were placed in the cold room for at least sixteen hours prior to applying solutions. Temperatures in the cold room varied from -10°F to 0°F during the tests. Deicing chemical solutions were applied in the cold room by brushing them onto the slab surfaces. The slabs remained in the cold room for a minimum of 30 minutes after applying the solutions. Prior to removing the slabs, the visual condition of the surfaces was recorded and a temperature reading was taken on the control slab.

Then slabs were moved to a humidity controlled room where observations were made and recorded at short-time intervals.

After all slabs had thawed and the surface temperatures had reached approximately 45°F, the slabs were retested with the British Portable Friction Tester.

Three applied dosages of chemicals were used on each set of slabs during subsequent tests. These were at 0.5, 1.0, and 1.5 ounces per square foot.

Results of tests indicate that the rate of application was critical for some chemicals, but not for others (as shown on Tables 4, 5, 6.). Most satisfactory at any rate of application were the TKPP solutions. They have relatively high specific gravities and are not quickly absorbed into the concrete or dried out through evaporation. Friction tests conducted in the lab did show some loss of skid resistance for the TKPP solutions; however, the test results for reasons previously mentioned were not considered conclusive. The main disadvantage of the British Portable Friction tests is the small area tested and poor reproducibility. For this reason, field tests were carried out using an ASTM type towed trailer skid tester.

Field Skid Tests

Tetra-potassium pyrophosphate was found to be one of the more effective chemicals tested for the purpose of preventing ice formation on concrete. Thus, it was decided to immediately implement a field testing program to determine its effect on the skid resistance of pavement.

Sections of approximately 200 foot lengths of concrete pavement were marked off for each test using the towed trailer skid tester. Each section of pavement was tested initially at a 40 MPH speed by the conventional procedure, using water. Solutions of sodium chloride and tetra-potassium pyrophosphate were then sprayed at various rates of application and the sections retested for skid resistance. Both 30% TKPP and 60% TKPP solutions were used in addition to a 25% sodium chloride solution. Additional tests were run on sections with sand applied over the solutions. Three rates of application of solutions ranging from light to heavy were tested. The results of these skid tests are shown on Table 7.

These tests were conducted on a concrete pavement surface which could be classified as fairly smooth and typical of the surfaces to be found on many bridge decks throughout the State. The average skid number of all test sections using plain water was 46.8 for a trailer speed of 40 MPH.

From the limited number of tests performed on this particular pavement surface, the following observations are noted:

1. 60% TKPP solutions at all application rates caused significant loss in skid resistance when no sand was applied to the pavement. It would not be recommended that this amount of solution be applied without sand. Only an application rate of less than .02 lb./sq.ft. at this 60% concentration might be suggested and this should be followed by a standard spread of sand. A standard spread of sand refers to the normal application rate used presently by maintenance personnel.

2. 30% TKPP solutions showed much more promising results. Without sand, only small decreases in skid resistance occurred. A standard application of sand broadcast over the solutions increased skid resistance. Use of a 30% solution concentration is proposed, the rate of application dependent on existing concrete and climatic conditions. A standard spread of sand should be applied in conjunction with the solution.

3. 25% sodium chloride solutions (saturated concentration) were tested for comparative results. Skid numbers quite similar to the 30% TKPP solutions were obtained on tests run immediately following application of the chemicals.

A significant observation was made during these field tests. All TKPP solutions remained longer on the pavement surface than did sodium chloride solutions. Sodium chloride solutions were more readily absorbed into the concrete and/or lost due to evaporation. This ability of TKPP solutions remaining longer on the surface may be an important feature in that the deicing ability is probably extended over a longer period of time.

After test sections sprayed with the TKPP solutions had eventually dried, the pavement was covered with a white deposit. This suggested that if the surface was rewetted with water or frost, snow or ice, perhaps its deicing ability would be restored.

Laboratory Concrete Tests

In order to determine if the alternative chemicals could adversely affect concrete, 84 cylinders (4-1/2 x 9-inch) with gage plugs at each end were subjected to various tests. The cylinders were made from two mix designs; one having 4-1/2 sacks of cement per cubic yard at 2-3/4-inch slump and 5.8% entrained air, and the other having 7 sacks of cement per cubic yard at 4-inch slump with 4.5% entrained air. All cylinders were cured for a minimum of 28 days by complete immersion in tap water at room temperature, then oven dried at 140°F for 28 days in a forced draft oven. One test was to then alternately immerse one-half or 42 cylinders in a saturated solution of the chemical for 7 days, and then subject them to oven drying at 140°F for 7 days. Changes in length were measured after each cycle by means of a comparator. The results of the length change measurements after 8 cycles of alternate immersion testing is shown on Figures 1 through 6. Weight measurements were made at similar times along with periodic observations and photographs. The other 42 specimens were partially immersed to a depth of 2 inches in the various solutions.

The following is a summary of the current results:

(a) Both 4-1/2 and 7-sack concrete cylinders are not significantly affected after 7 cycles of wet-dry tests in tap water.

(b) Sodium formate caused severe deterioration of both 4-1/2 and 7-sack concrete specimens. Visible surface scaling was evident after only two cycles. Figure 7 shows the condition of 4-1/2-sack concrete specimens after removing them from solutions at the completion of the wet portion of the fourth cycle. Crystal growth and severe disintegration is obvious. Only one more cycle was possible before terminating tests employing sodium formate because of the extreme disintegration of the concrete.

(c) Concrete cylinders cycled in a saturated sodium chloride solution were first observed to have scaling of the surfaces of all cylinders after the third cycle. This scaling has not become severe through 7 cycles and is believed to be primarily confined to the surface area, and not of major concern yet to the structural strength of the concrete. The distress observed is similar to that occurring in normal air entrained concrete exposed to similar salt concentrations.

(d) Thus far, observations of the test with the saturated solution of tetra-potassium pyrophosphate has not produced any noticeable detrimental effect on concrete after three cycles; however, not enough data is available at this time to make any conclusions on the long-term effect of the chemical.

Figures 7, 8, and 9 show the appearance of 4-1/2-sack concrete after four cycles of alternate immersion and oven drying. Figures 10 and 11 show the amount of concrete disintegration after five and six cycles of alternate immersion in sodium formate for the 4-1/2 and 7-sack concrete.

Corrosion Tests

One of the most important properties of any candidate deicing chemical which may be considered as a substitute for sodium chloride is that it be noncorrosive to reinforcing steel in bridge decks, or at least only slightly corrosive if it is not possible to find a completely noncorrosive chemical.

With this in mind, a simple corrosion screening test was chosen to evaluate the corrosivity of the various concentrations of chemical solutions. The method used was to immerse mild steel corrosion probes in the solutions and measure the corrosion rate of the steel by means of the change in the electrical resistance of a thin metal strip. The change in the electrical resistance of the strip is caused by any loss in metal cross-section as corrosion proceeds. The equipment used to measure the corrosion rate of steel in the solution is shown on Figure 12.

Upon completion of each corrosion test, the pH of each solution was determined. Some of the results of corrosion and pH tests are shown in Table 8. The corrosion tests were run on each chemical when dissolved in distilled water and also in lime-saturated distilled water. Tests using lime-saturated water are believed to simulate conditions found in concrete where the pH of salt-free concrete is about 12 or 13. The corrosion test probes were normally submerged in each test solution for 3 days. For the probe immersed in distilled water, its corrosion rate was 7.2 mils per year. For the probe immersed in the lime or calcium hydroxide solutions, the corrosion rate was 0.6 mils per year.

Some important indications resulting from these corrosion tests that have become apparent are (a) no completely noncorrosive deicing chemical has been tested; (b) tetra-potassium pyrophosphate produced the most promising results when tested in saturated lime water solution insofar as a minimum corrosion rate was observed; (c) sodium chloride solutions in lime-saturated distilled water gave higher corrosion rates than corresponding solutions in plain distilled water. This occurred at 2, 4, 8, and 16% solutions; and (d) urea and sodium formate solutions in lime water at 1% solution concentrations were found to be fairly corrosive but almost noncorrosive at all higher concentrations.

Ecology and Toxicity

Recently there has been quite an increase of interest in the effect of deicing salts on plant life[10,11,12]. As a result, this investigation of alternative deicing chemicals also included emphasis on the effect of these new materials on the ecology. Several agencies and individuals were asked to comment on various chemicals. Only a few of the many comments received will be discussed in this report.

A. Toxicity

In a private communication, a representative of the California State Environmental Health and Consumer Protection Program has related that the same precautions should be used when handling tetra-potassium pyrophosphate as is used for sodium and calcium chloride. Urea should not have any adverse affect on humans.

B. Ecology

In a private communication with the College of Agriculture, University of California, Davis, dated September 3, 1969, a professor stated that sodium and calcium chloride have resulted in soil conditions in the East which is toxic to most plants. Urea should not cause any toxicity to plants unless used in large quantities, except it might stimulate an undesirable growth along the highway. Tetra-potassium pyrophosphate should give the least trouble from a residue standpoint because it should be tied up by the soil and be unavailable for plants.

In a private communication dated November 4, 1969, from the Regional Forester's office for the U. S. Department of Agriculture, Forest Service, an opinion was offered that the urea material could leach into streams and lakes and cause an increase in algae or other aquatic plant growth. It was also stated that urea or tetra-potassium pyrophosphate would not be as damaging to the roadside environment as the presently used calcium and sodium chlorides.

In written communication with the U. S. Department of Agriculture, Soil Conservation Service, dated July 28, 1969, an opinion was given that extremely high concentrations of urea would kill all plants next to the roadway, but the greatest hazard is to streams and lakes wherein it could greatly increase plant growth and add to pollution. The opinion was also given that tetra-potassium pyrophosphate would be the least hazardous to plants, and it adds little to a pollution problem. This is because this material would be applied to normally acid soils where snow and ice occur and would thus be fixed by the soil.

Consideration should also be given to the influence of nitrogen compounds on the nitrate buildup in ground water. Currently, the California State Department of Public Health is studying the toxic effects of nitrates in drinking water from wells on infants under six months of age[14].

DISCUSSION

The studies of alternative deicing salts are not complete. Many chemicals that have been tested in one phase of the program have not been tested in other phases. The reason is that it is most urgent to find a relatively non-corrosive salt at a reasonable cost at the earliest date.

During the investigation, sodium formate had an ice melting capability that was nearly equal to the chlorides. However, it was found in the alternate immersion tests that concrete would be rapidly attacked. Rather than continuing the testing of this chemical which would necessarily include finding means of offsetting its aggressiveness to concrete, attention was diverted to other chemicals that did not exhibit this characteristic. It is intended to retrace and continue some of the research steps with some of the less costly deicing chemicals if the alternative chemicals do not fit all requirements. However, this would probably mean testing many combinations of chemicals and that type of investigation is not one that usually gives rapid results.

As indicated by the contents of this report, it appears that urea and tetra-potassium pyrophosphate are among the better candidates tested as alternative deicing chemicals. However, they may need to be modified to reduce this corrosivity to steel. It is believed that the phosphate may be mixed with lime and thus be rendered relatively noncorrosive to steel. However, it is anticipated that the lime-phosphate mixture will still be somewhat corrosive to zinc and aluminum.

As indicated by the tests, urea in water is corrosive to steel. At certain concentrations, our tests and as reported by others, urea appears to be more corrosive to steel than salt[13]. The combination of urea, lime and water significantly reduces the corrosive action to steel. However, there is some concern about the corrosive properties of urea on bridge decks which have cracked concrete and its possible effect on plant life. Urea is a nitrogen compound, and coupled with the soil in the cracks, there is a significant possibility that the urea could be reduced by bacterial action to highly corrosive nitrates. Also it appears that urea and other nitrogen compounds could offer the greatest hazard in stimulating algae growth in the adjacent streams. Because of possible effects on the environment, controls may be necessary to govern the use of fertilizer types of materials in certain geographic areas.

The work that is reported herein is not complete. Our research effort will continue in evaluating alternative chemicals both in the laboratory and in the field.

BIBLIOGRAPHY

Corrosion of Bridge Steel

1. "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures"
NCHRP Report 1, HRB 1963
By Bertram D. Tallamy Associates, Consulting Engineers

2. Boies, David B. and S. Bortz
"Economical and Effective Deicing Agents for Use on Highway Structures"
NCHRP Report 19, HRB 1965

3. Tripler, Arch B.; Earl L. White; F. H. Hayne; and W. K. Boyd
"Methods for Reducing Corrosion of Reinforcing Steel"
NCHRP Report 23, HRB 1966

4. Freyermuth, Clifford L.; Paul Klieger, David Stork, and Harry N. Wenke
"Durability of Concrete Bridge Decks: A Review of Cooperative Studies."
A paper presented at the 49th Annual Meeting, HRB, Jan. 1970

5. Spellman, Donald L., and R. F. Stratfull
"Chlorides and Bridge Deck Deterioration"
A paper presented at the 49th Annual Meeting HRB, Jan. 1970

6. Hearst, Peter J.
"Deicing Materials for Military Runways"
Project NY 000 003-4.02, Technical Memo M-124, U.S.N.C.E.L. Port Hueneme, Calif., Mar. 1, 1957

7. Hovey, G. E., J. C. Caird, and G. A. Dalby
"1966-67 Urea Test Program"
Report 1958, Cont. F33657-67-C-0491, RCAF, Central Experimental Proving Establishment, Ottawa, Ontario, Canada, Nov. 1967

8. Feiler, W. A.
"A Study of Cost, Ice Melting, and Corrosion Characteristics of Several Chemical Deicers"
Special Report No. 6573, Monsanto Company, Inorganic Chemicals Division, Research Department, St. Louis, Missouri, Jan. 5, 1966

9. Harris, J. C.; J. R. Gibson; and C. Street
"Chemical Means for Prevention of Accumulation of Ice, Snow, and Slush on Runways"
Monsanto Research Corporation
Final Report SRDS No. 65-13, Cont. FA WA4577, Mar. 1965

10. Zelazny, L. W.
"Effects of Deicing Salts on Roadside Soils and Vegetation"
NCHRP 16-1, Fiscal Year 1966, Final Report

11. Sauer, G.
"On Damages by Deicing Salts to Plantings Along the Federal Highways"
News Journal of the German Plant Protection Service, 19(6), 1967

12. Button, E. F.; and D. E. Peaslee
"The Effect of Rock Salt upon Roadside Sugar Maples in Connecticut"
HRB Record 161, 121-131, 1967

13. Nelson, G. A.
"Corrosion Data Survey"
1967, copyrighted 1968 by National Association of Corrosion Engineers, Houston, Texas

14. California State Department of Public Health
Study on Toxicity of Nitrates in Drinking Water from Wells on Infants Less than 6 Months of Age, Sacramento Bee, Sacramento, California, publication of Thursday, October 16, 1969

Table 1
Depth of Ice Melting by Dry Powders at 10°F

Chemical	"n"	Equation	Coeff. of Correlation	Std. Error of Estimate Inches
Sodium Chloride	4	$Y=0.297Log_{10}X+0.234$	0.996	.010
Calcium Chloride	4	$Y=0.124Log_{10}X+0.221$	0.937	.018
Sodium Formate	3	$Y=0.270Log_{10}X+0.216$	0.977	.023
TKPP	5	$Y=0.039Log_{10}X+0.069$	0.949	.006

Note: Y = depth of ice melted, inches X = time in hours
Chemical spread at 0.25 lb./sq.ft.

Table 2
Depth of Ice Melting by Dry Powders at 17°F

Chemical	"n"	Equation	Coeff. of Correlation	Std. Error of Estimate Inches
Sodium Chloride	12	$Y=.185Log_{10}X+.245$	0.925	.049
Calcium Chloride	5	$Y=.161Log_{10}X+.239$	0.992	.009
Sodium Formate	12	$Y=.145Log_{10}X+.206$	0.911	.042
TKPP	6	$Y=.062Log_{10}X+.090$	0.953	.010
Urea	11	$Y=.074Log_{10}X+.113$	0.854	.026

Note: Y = depth of ice melted, inches X = time in hours
Chemical spread at 0.25 lb./sq.ft.

Table 3
Depth of Ice Melting by Dry Powders at 24°F

Chemical	"n"	Equation	Coeff. of Correlation	Std. Error of Estimate Inches
Sodium Chloride	12	$Y=0.444Log_{10}X+.467$	0.992	.040
Calcium Chloride	12	$Y=0.250Log_{10}X+.347$	0.995	.018
Sodium Formate	12	$Y=0.412Log_{10}X+.434$	0.997	.023
TKPP	12	$Y=0.096Log_{10}X+.145$	0.961	.019
Tripotassium Phosphate	5	$Y=0.147Log_{10}X+.179$	0.993	.008
Sodium Acetate	5	$Y=0.146Log_{10}X+.179$	0.988	.001
Urea	7	$Y=0.212Log_{10}X+.227$	0.993	.014
Sodium Benzoate	4	$Y=0.214Log_{10}X+.199$	0.973	.021

Note: Y = depth of ice melted, inches X = time in hours
Chemical spread at 0.25 lb./sq.ft.

Table 4

Deicing Ability of Chemical Solutions on Concrete Slabs
Application Dosage = 0.5 fl.oz./sq.ft.

Deicing Chemical	% Solution (By Weight)	Temp. (°F)[1] Frost	Ice	Wt./Sq.Ft. of Chemical (Lbs.)	British Portable Friction Readings[2] Initial	After 1st Cycle
TKPP	60	+20	None	.034		
TKPP	30	+29	None	.014	73	63
TKPP + formamide	50-10	None	None	.032		
TKPP + formamide	25-5	+24	None	.013	72	72
Urea	20	+32	+32	.007		
Urea	40	+24	+20	.015		
Sodium chloride	10	+32	+28	.004		
Sodium chloride	25	+32	None	.010		
Form-Urea-H_2O	75-20-5	+32	None	.029		
Form-Urea-H_2O	50-40-10	+32	+15	.019		
Sodium benzoate	25	+32	+20	.009		
Sodium benzoate	37	+24	+10	.014		
Urea+calcium form.	17-8	+32	+28	.008	70	70
Calcium chloride	30	+30	None	.013	69	71
Magnesium sulfate	20	+31	+29	.008	70	71
Sodium formate	25	+32	None	.010	66	60
Plain slab	0	+32	None	0	62	60

[1] Temperatures on the surface of the untreated slabs, above which no frost or ice formed on the chemically treated slab, for the 1st cycle.

[2] Each reading is the average of three test readings.

Slabs were all initially cooled to -0°F

Table 5

Deicing Ability of Chemical Solutions on Concrete Slabs
Application Dosage = 1.0 fl.oz./sq.ft.

Deicing Chemical	% Solution (By Weight)	Temp. (°F)[1] Frost	Temp. (°F)[1] Ice	Wt./Sq.Ft. of Chemical (Lbs.)	British Portable Friction Readings[2] Initial	British Portable Friction Readings[2] After 1st Cycle
TKPP	60	None	None	.068	61	55
TKPP	30	+29	None	.028	70	53
TKPP + formamide	50-10	None	None	.063	67	61
TKPP + formamide	25-5	+25	None	.026	72	61
Urea	20	+32	+30	.014	72	73
Urea	40	+28	+22	.030	72	74
Sodium chloride	10	+32	+22	.008	69	70
Sodium chloride	25	None	None	.020	75	72
Form-Urea-H_2O	75-20-5	+31	None	.058	52	54
Form-Urea-H2O	50-40-10	+30	+ 5	.040	65	62
Sodium benzoate	25	+19	+ 6	.018	72	68
Sodium benzoate	37	+12	+ 4	.028	68	65
Urea + Calcium form.	17-8	+32	+26	.016	70	66
Calcium chloride	30	+29	None	.026	69	60
Magnesium Sulfate	20	+30	+24	.016	70	61
Sodium formate	25	+32	None	.020	68	63
Plain slab	0	+32	None	0	62	62

1 Temperatures on the surface of the untreated slabs, above which no frost or ice formed on the chemically treated slab for the 1st cycle.

2 Each reading is the average of three test readings.

Slabs were all initially cooled to -0°F.

Table 6

Deicing Ability of Chemical Solutions on Concrete Slabs
Application Dosage = 1.5 fl.oz./sq.ft.

Deicing Chemical	% Solution (By Weight)	Temp. (°F)[1] Frost	Temp. (°F)[1] Ice	Wt./Sq.Ft. of Chemical (Lbs.)	British Portable Friction Readings[2] Initial	British Portable Friction Readings[2] After 1st Cycle
TKPP	60	None	None	.102	61	50
TKPP	30	+30	None	.042	73	49
TKPP + formamide	50-10	None	None	.096	67	49
TKPP + formamide	25-5	None	None	.039	72	57
Urea	20	+32	+20	.021	72	73
Urea	40	+30	+18	.045	72	71
Sodium chloride	10	+32	+17	.012	69	75
Sodium chloride	25	None	None	.030	75	77
Form-Urea-H_2O	75-20-5	None	None	.087	52	49
Form-Urea-H_2O	50-40-10	0	None	.057	65	63
Sodium benzoate	25	+20	0	.027	72	68
Sodium benzoate	37	+12	0	.042	68	56
Urea + Calcium form.	17-8	+32	+12	.024	70	66
Calcium chloride	30	None	None	.039	69	58
Magnesium sulfate	20	+32	+15	.024	70	56
Sodium formate	25	+25	None	.030	62	59
Plain slab	0	+32	None	0	62	60

[1] Temperatures on the surface of the untreated slabs, above which no frost or ice formed on the chemically treated slab, for the 1st cycle

[2] Each reading is the average of three test readings

Slabs were all initially cooled to -0°F

Table 7

Skid Test Results

Concrete Pavement Section Number	Solution Tested (Lbs. by Weight)	Rate of Application, Lbs. Chemical/Sq.Ft. Pavement	Sand Applied No	Sand Applied Yes (Rate)	Skid No. with Water Only	Skid Number Immediately Following Solution Application	Skid Number At Time Shown in Parenthesis After Solution Application
1	60% TKPP	.032	X		48.2	29.0	----
2	"	.022	X		46.3	30.9	33.8 (1.5 hr.)
3	"	.039		Standard	46.3	38.6	39.0 (")
4	"	.070		Standard	45.8	35.7	37.6 (")
5	"	.014		Light	47.2	46.3	30.6 (")
1	30% TKPP	.012	X		48.2	44.3	70.7 (1.5 hr.)
2	"	.018	X		46.3	44.3	64.6 (")
3	"	.034	X		46.3	44.3	48.7 (")
4	"	.014		Standard	45.8	48.2	55.0 (1.0 hr.)
5	"	.018		Standard	47.2	46.3	53.1 (")
6	"	.036		Standard	50.1	46.3	47.2 (")
7	"	.057		* *	43.4	41.4	41.0 (0.5 hr.)
9	"	.062		***	47.7	40.5	43.4 (")
1	25% NaCl	.010	X		48.2	57.0	67.2 (1.5 hr.)
2	"	.017	X		46.3	43.8	59.1 (")
3	"	.025	X		46.3	44.3	46.3 (")
4	"	.009		Standard	45.8	48.2	54.5 (1.0 hr.)
5	"	.017		Standard	47.2	42.9	48.7 (")
6	"	.020		Standard	50.1	40.5	41.9 (")
7	"	.036		Standard	43.4	42.9	42.9 (0.5 hr.)
9	"	.042		*	47.7	43.4	47.2 (")

* Standard application before solution applied
** Heavy application after solution applied
*** Heavy application before solution sprayed

Table 8

Corrosion Test Results

Solution	Solutions in Distilled Water								Solutions in Lime Saturated Distilled Water							
	Sodium Chloride		Urea		Sodium Formate		TKPP**		Sodium Chloride		Urea		Sodium Formate		TKPP	
% By Wt.	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH	Mils	pH
1	1.6	7.2	6.6	7.2	2.0	8.4	0.5	9.5	1.5	11.6	3.8	12.0	3.1	11.7	0.3	12.3
2	1.5	7.1	1.9	7.2	2.9	7.2	1.2	9.5	4.5	11.4	0.6	12.4	0.6	11.6	0.4	12.6
4	1.6	7.0	2.6	7.6	1.8	7.4	1.3	9.4	3.6	11.2	0.0	12.5	0.5	11.3	1.0	12.3
8	1.1	6.9	6.5	7.6	1.4	7.5	3.7	9.4	2.6	10.9	0.2	12.2	0.7	11.2	0.7	12.1
16	2.1	6.9	5.4	7.8	1.0	7.6	4.0	9.3	2.6	10.9	1.4	12.3	0.3	11.2	0.5	12.3
30	1.0	7.0	3.9	8.0	0.0	7.6	0.8	9.5	0.0	10.2	*	12.3	0.0	10.8	0.4	11.8

* Reading not obtained because of damaged probe

** TKPP - tetra-potassium pyrophosphate

Note: Mils is corrosion rate in mils per year

pH is hydrogen-ion concentration after test

Figure 1

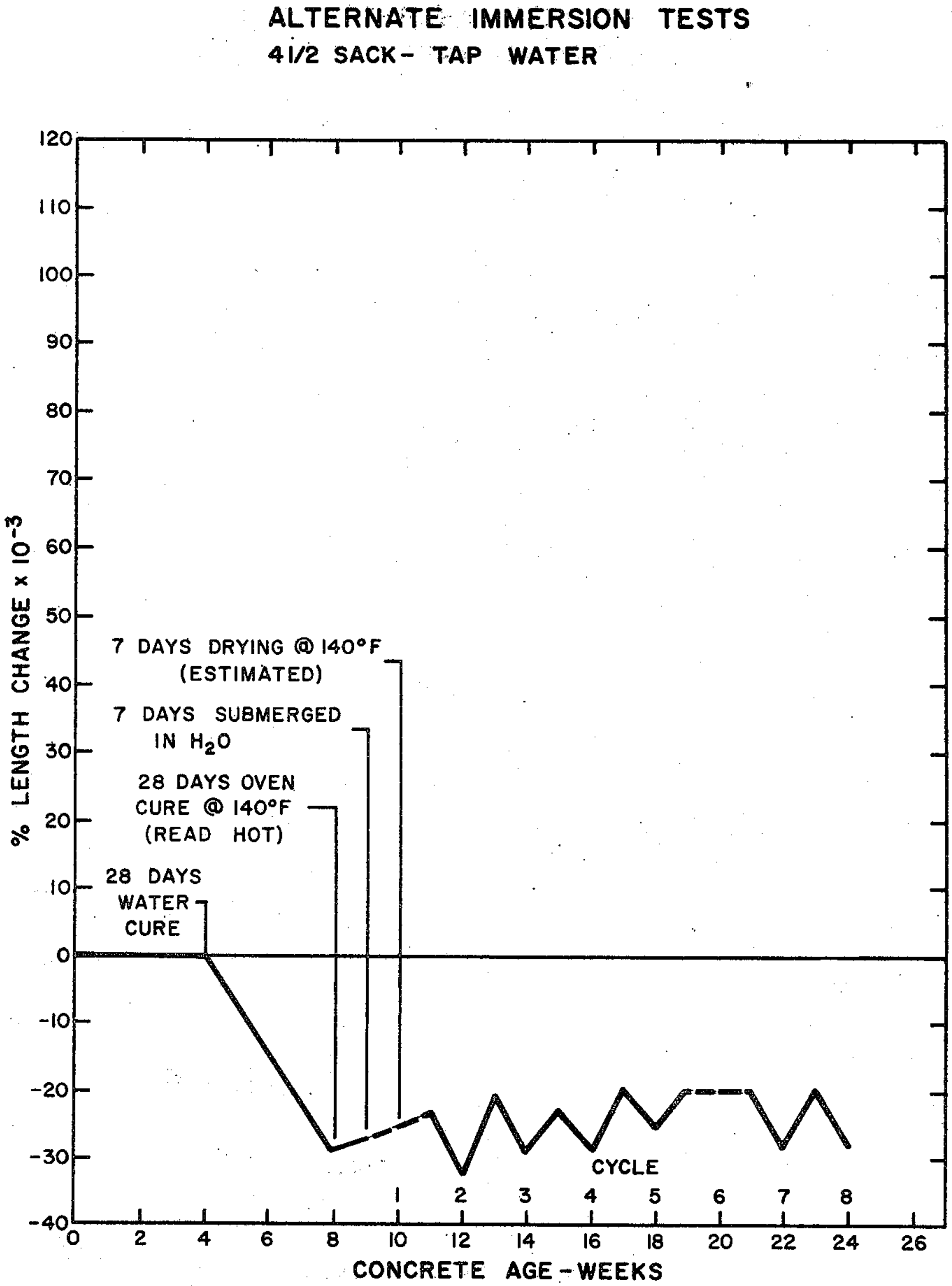

ALTERNATE IMMERSION TESTS
4 1/2 SACK - TAP WATER
% LENGTH CHANGE x 10^-3
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
7 DAYS DRYING @ 140°F (ESTIMATED)
7 DAYS SUBMERGED IN H2O
28 DAYS OVEN CURE @ 140°F (READ HOT)
28 DAYS WATER CURE
CYCLE
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
CONCRETE AGE - WEEKS

Figure 2

ALTERNATE IMMERSION TESTS
7 SACK - TAP WATER

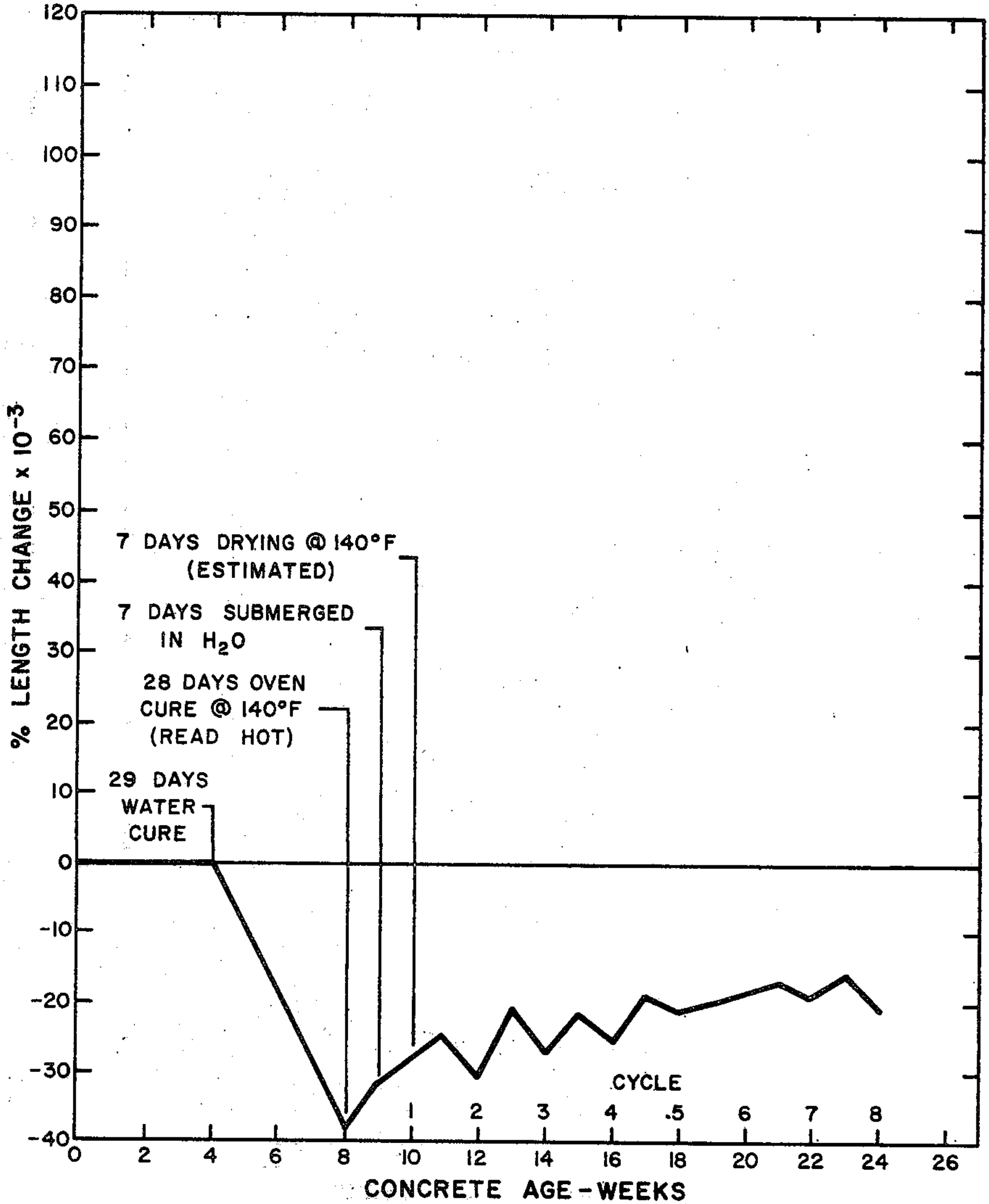


Figure 3

ALTERNATE IMMERSION TESTS
4 1/2 SACK-SODIUM CHLORIDE SOLUTION

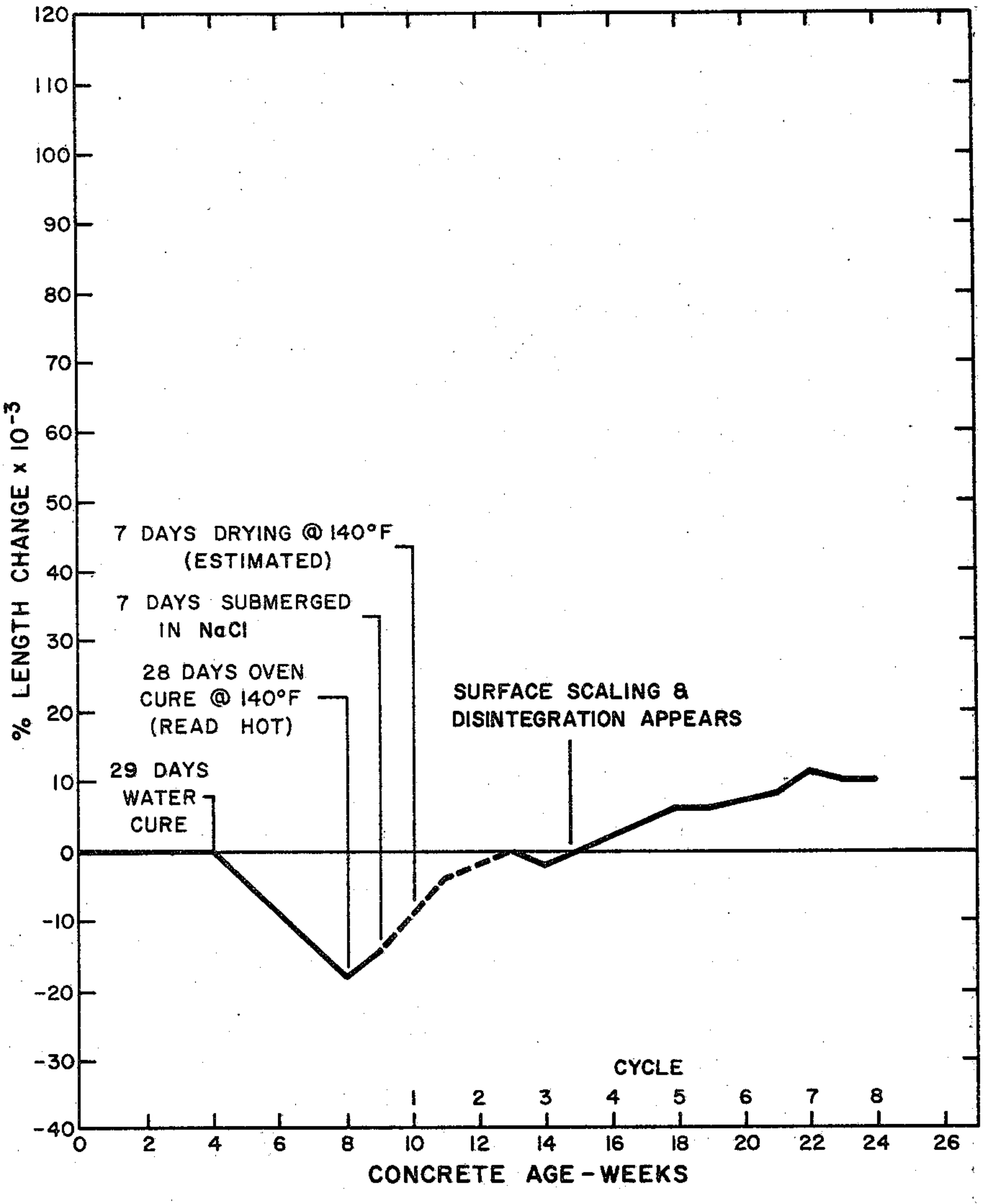


Figure 4

ALTERNATE IMMERSION TESTS
7 SACK-SODIUM CHLORIDE SOLUTION

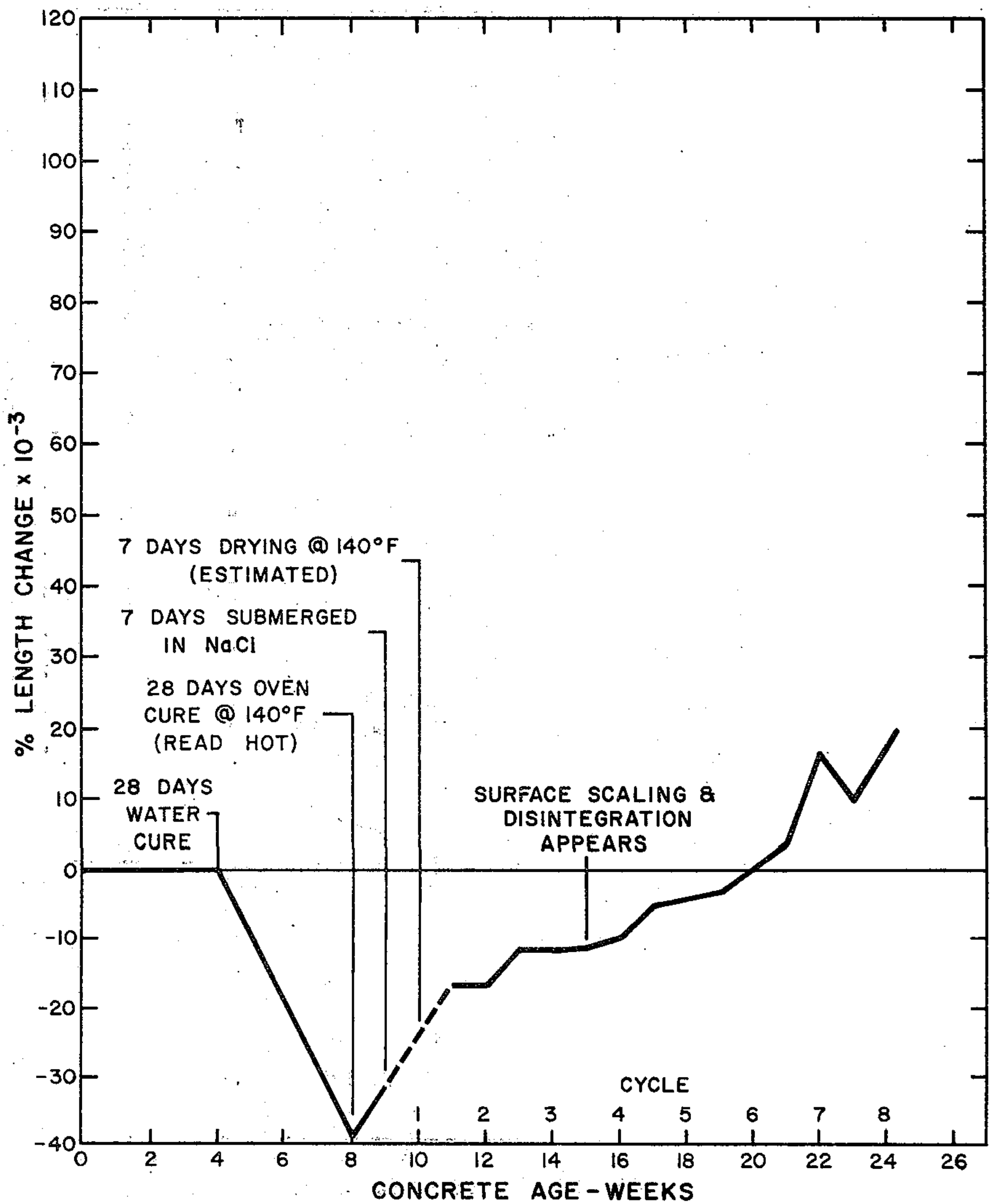


Figure 5

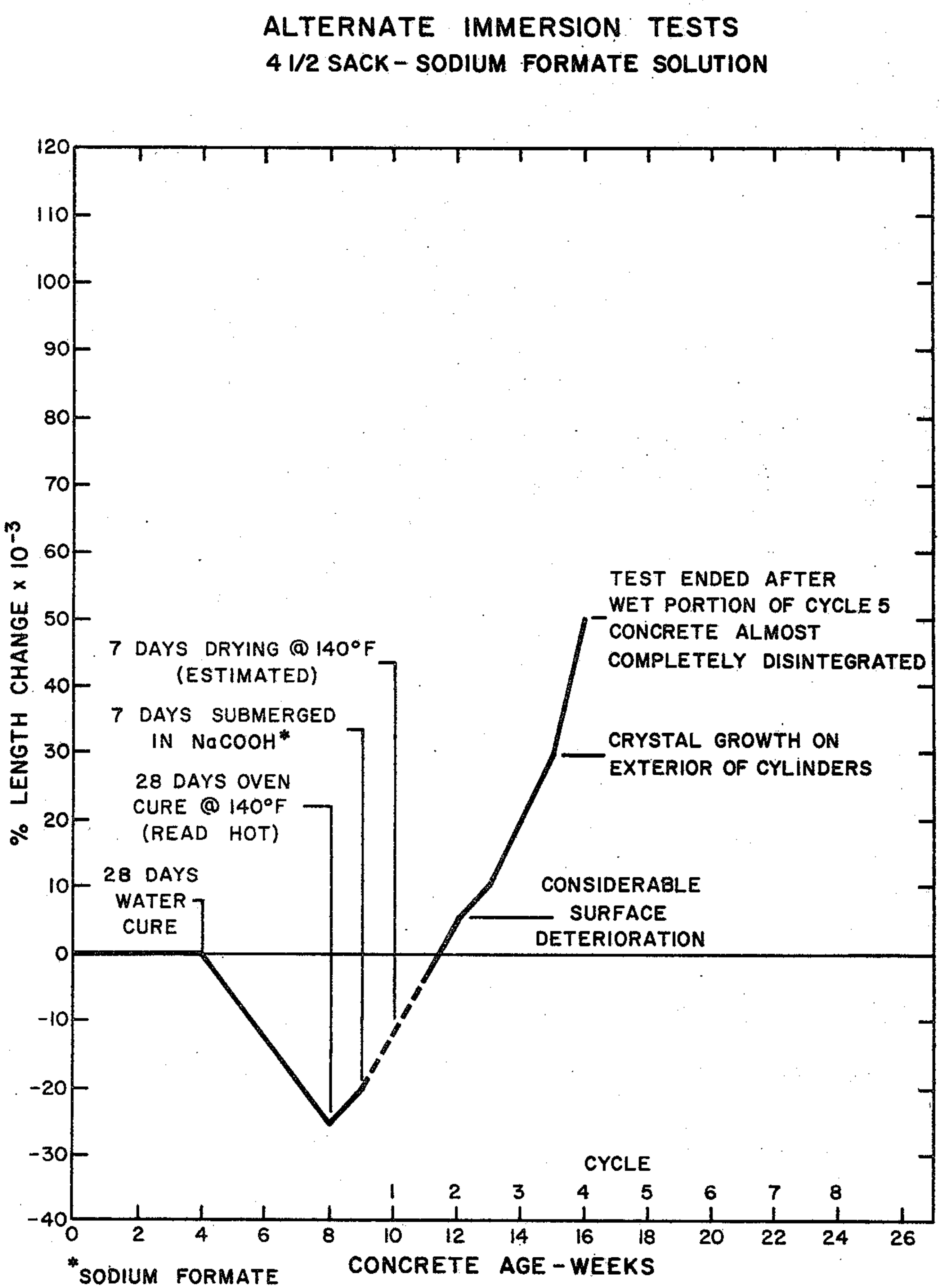
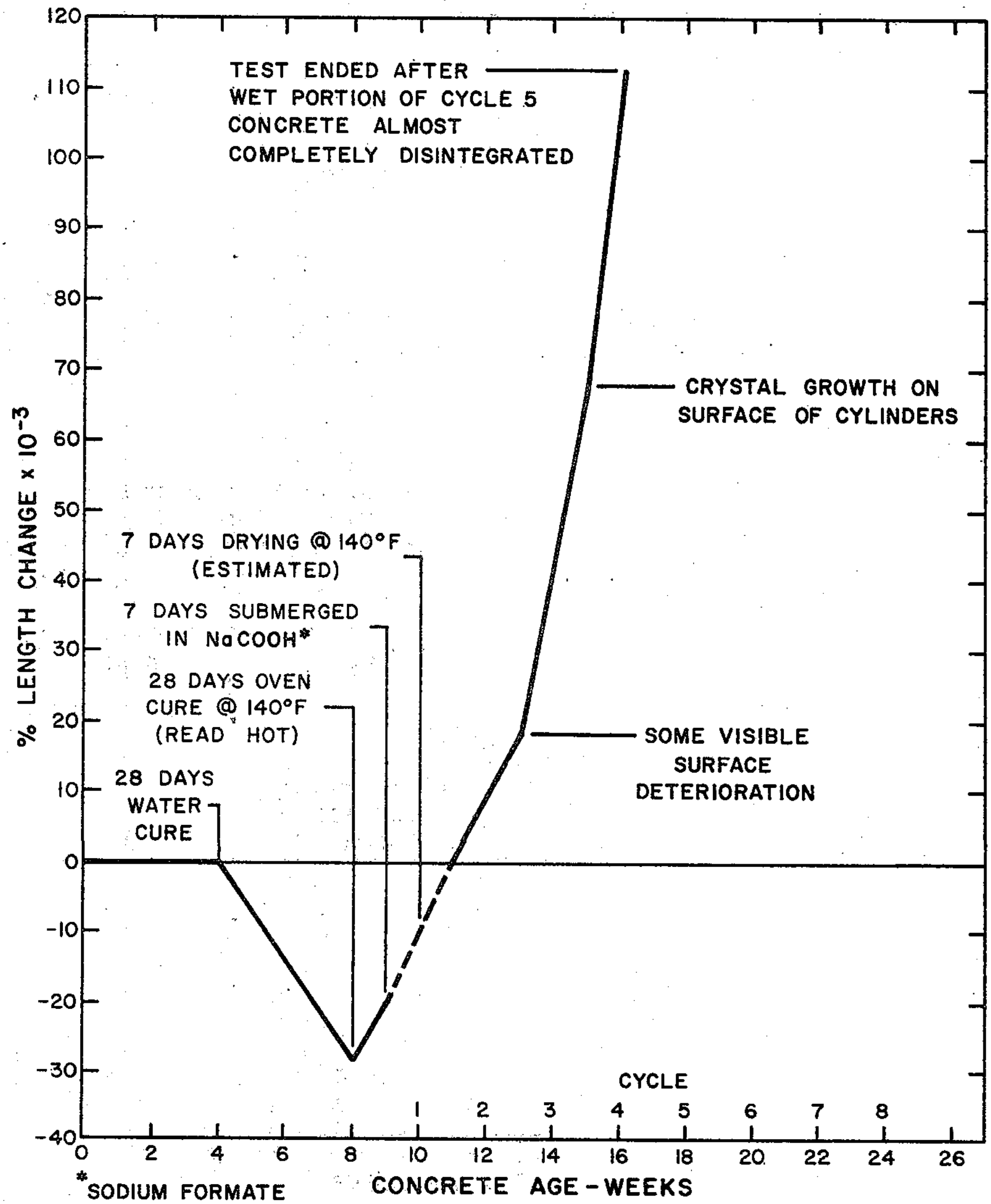

ALTERNATE IMMERSION TESTS
4 1/2 SACK - SODIUM FORMATE SOLUTION
% LENGTH CHANGE x 10-3
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
TEST ENDED AFTER WET PORTION OF CYCLE 5 CONCRETE ALMOST COMPLETELY DISINTEGRATED
7 DAYS DRYING @ 140°F (ESTIMATED)
7 DAYS SUBMERGED IN NaCOOH*
CRYSTAL GROWTH ON EXTERIOR OF CYLINDERS
28 DAYS OVEN CURE @ 140°F (READ HOT)
28 DAYS WATER CURE
CONSIDERABLE SURFACE DETERIORATION
CYCLE
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
*SODIUM FORMATE
CONCRETE AGE - WEEKS

Figure 6

ALTERNATE IMMERSION TESTS

7 SACK - SODIUM FORMATE SOLUTION



*SODIUM FORMATE

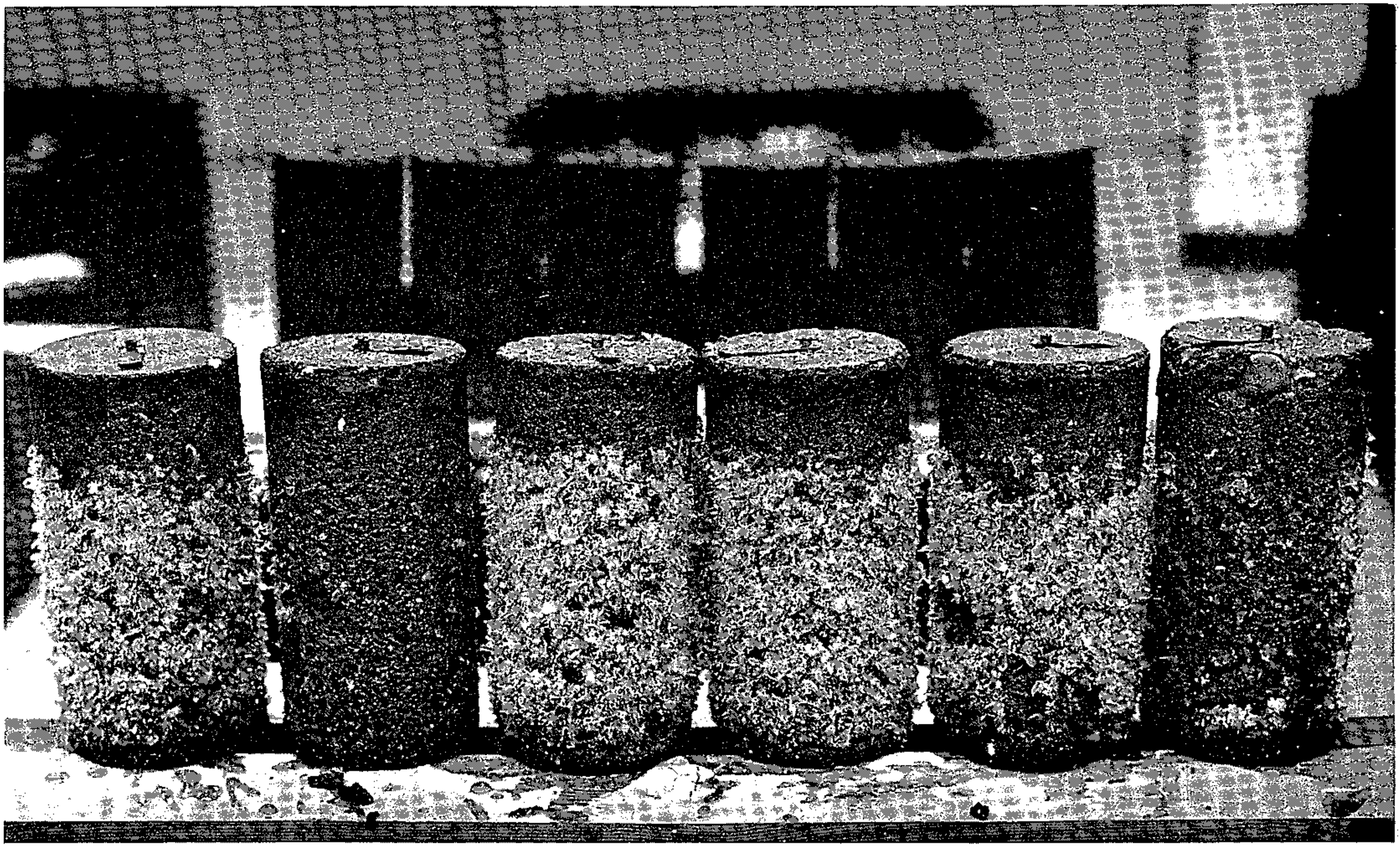


Figure 7. 4-1/2-sack concrete after four cycles of alternate immersion in sodium formate and oven drying

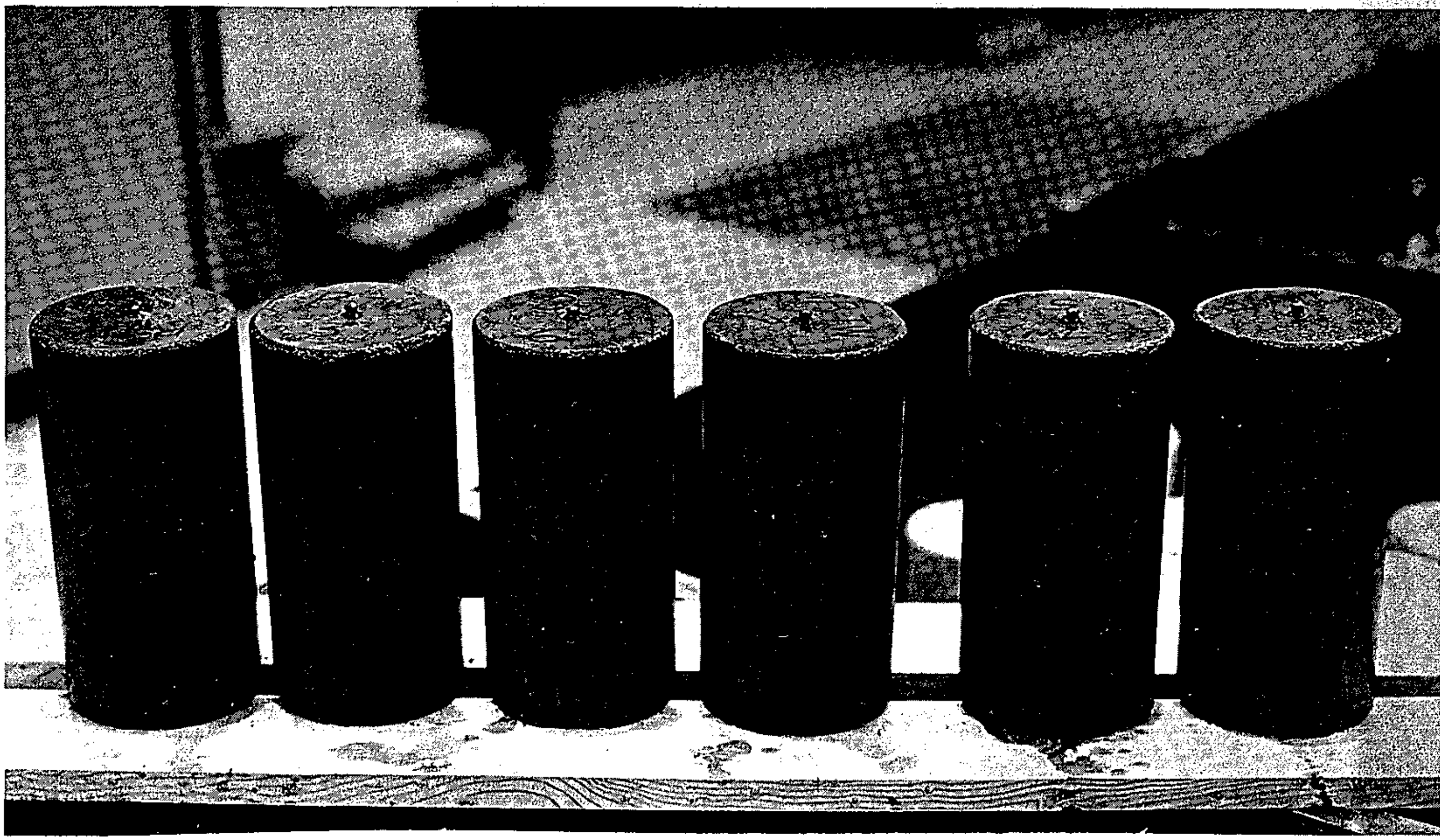


Figure 8. 4-1/2-sack concrete after four cycles of alternate immersion in tap water and oven drying

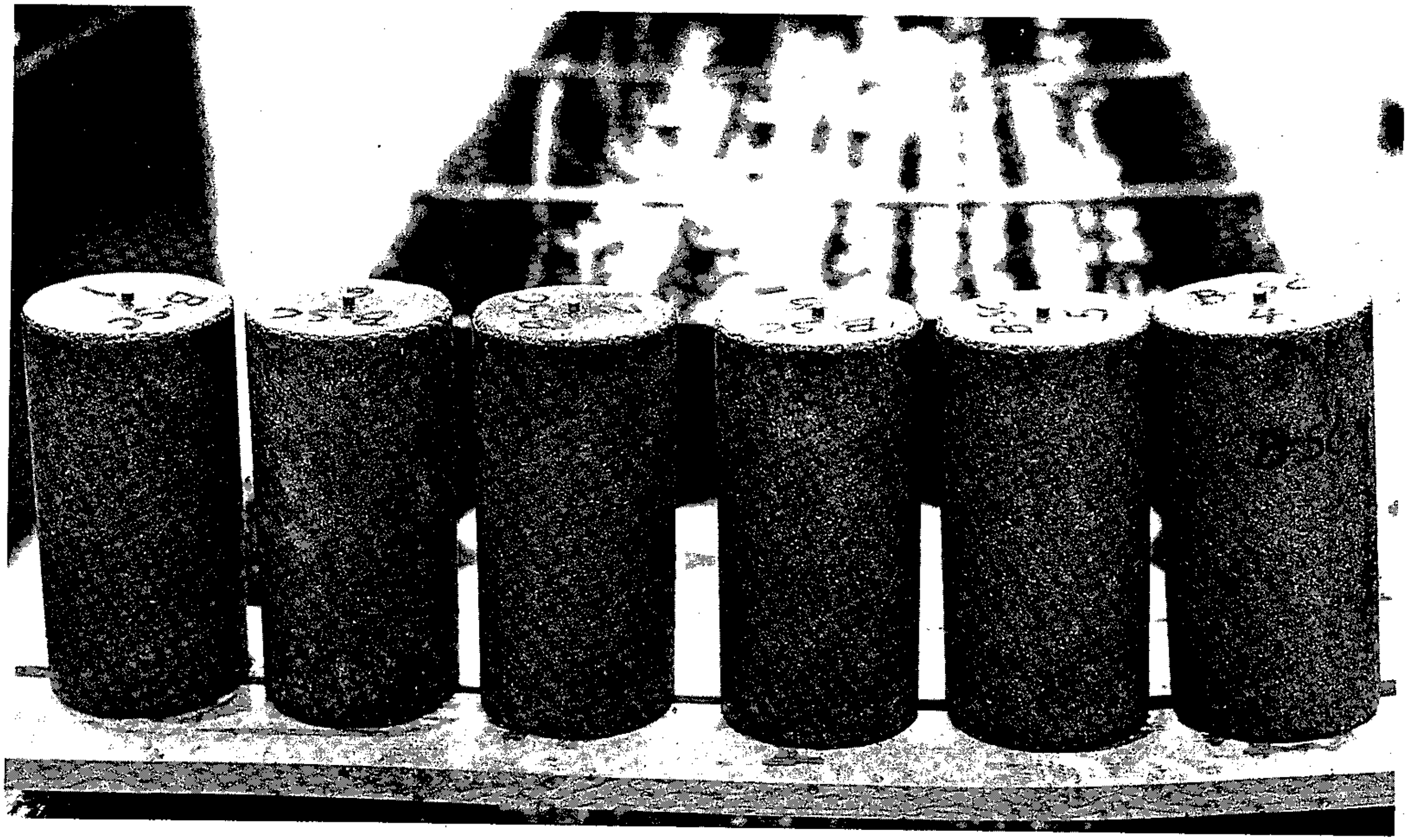


Figure 9. 4-1/2-sack concrete after four cycles of alternate immersion in sodium chloride and oven drying

Figure 10. Amount of concrete deterioration after five and six cycles of alternate immersion in sodium formate for 4-1/2-sack concrete

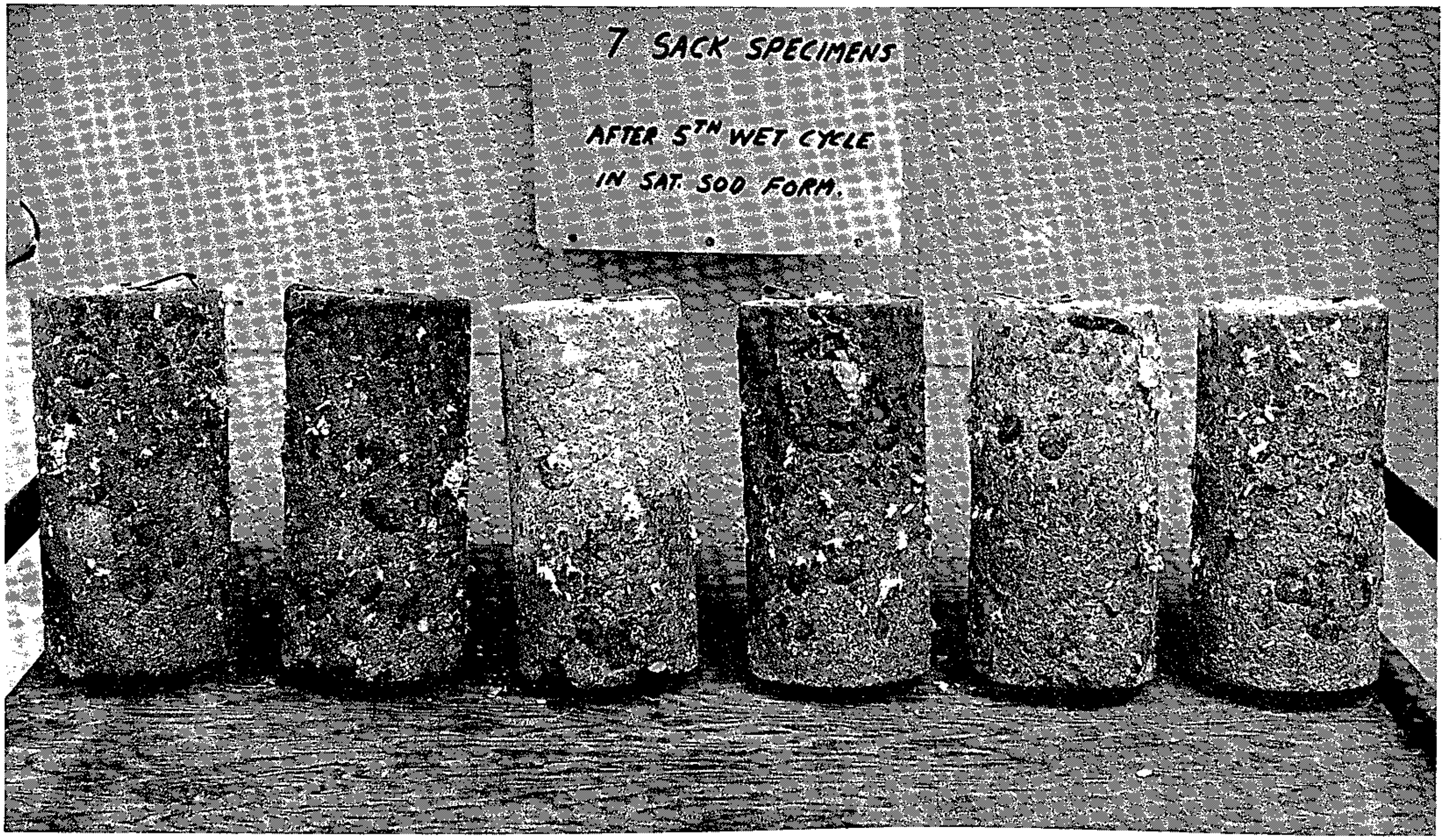


Figure 11. Amount of concrete deterioration after five and six cycles of alternate immersion in sodium formate for 7-sack concrete

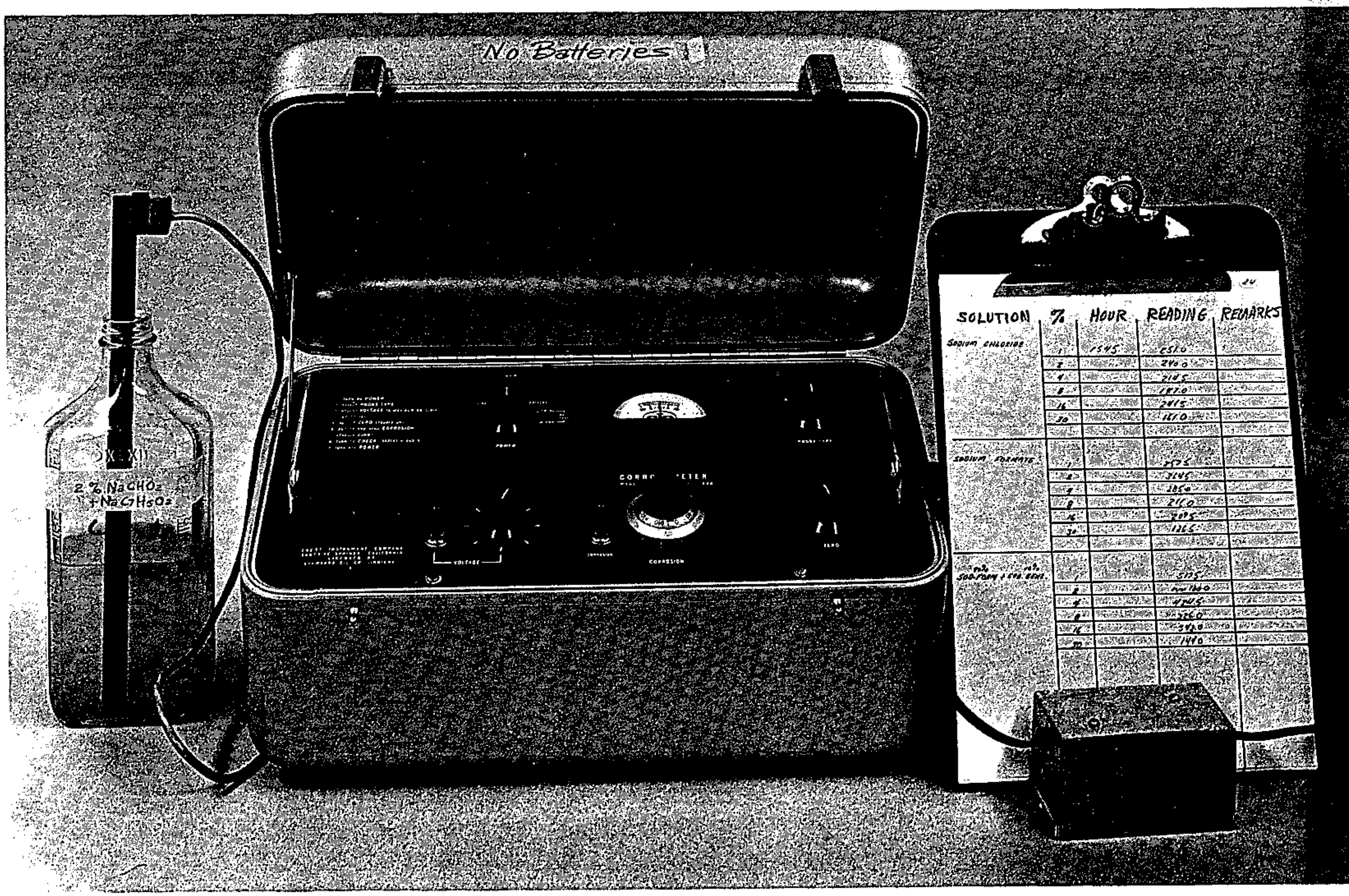


Figure 12. Corrosometer Testing Apparatus